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12

COMPARISON OF SLANT AND RUNWAY VISUAL RANGE RELATIONSHIPS FOR 100, 124, AND 155 FEET

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FINAL REPORT

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METRIC CONVERSION FACTORS

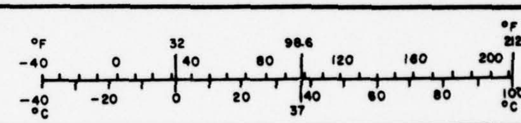
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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16. Abstract

Ratios of slant visual range measured from heights of 100, 124, and 155 feet to horizontal visual range measured at 15 feet were computed for low-visibility regimes. These ratios were found to be related to the linear fog density profile expressed as the difference in horizontal atmospheric transmittance between the top (100-, 124-, and 155-foot) and bottom (15-foot) levels. It was determined that useful estimates of slant visual range could be provided through these relationships. The predictions would be most accurate when the visibility decreased with height (most common fog structure). A slight increase in accuracy would also be expected with decreasing slant height. This effort was undertaken to extend an original investigation, "Slant and Runway Visual Range Relationships," published as report FAA-RD-77-34, June 1977.

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PREFACE

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INTRODUCTION

OBJECTIVE.

The objective of this report is to compare ratios of slant visual range (SVR) measured from 100, 124, and 155 feet to horizontal visual range measured at 15 feet, for various fog structures. The fog structure was determined by the linear fog density profile expressed as the horizontal atmospheric transmittance difference between the top (100-, 124-, and 155-foot) and bottom (15-foot) levels.

BACKGROUND.

The relationship between the ratio of SVR measured from 155 feet and horizontal visual range measured at 5 feet, and the linear fog density profile with height has been investigated at the National Aviation Facilities Experimental Center (NAFEC) and reported (Lewis and Schlatter, 1977). The results showed that average ratios of slant to horizontal visual range were increasingly less than 1 (ranging from about 0.75 to 0.45) when the 155-foot horizontal atmospheric percent transmittance was 10 to 30 percent, 30 to 50 percent, or more than 50 percent less than the 5-foot horizontal percent transmittance. The standard deviations of average ratios were mostly less than 0.1, indicating a good potential for predicting the ratios.

The average ratios were found to be near 1 when the 155- and 5-foot horizontal percent transmittances were within 10 percent of each other. Standard deviations were about 0.2, indicating some predictive potential in terms of the ratio being "about 1."

The average ratios were increasingly greater than 1 (ranging from about 2 to 5) when the 155-foot horizontal percent transmittance was 10 to 30 percent, 30 to 50 percent, or more than 50 percent higher than the 5-foot horizontal percent transmittance. Standard deviations were about 1 to 3, indicating low predictive potential for the ratio, other than to say that the slant visual range would be greater than the horizontal visual range.

The 155-foot slant and horizontal transmittances and 5-foot horizontal transmittance were converted to visual range using Allard's Law for runway light setting 4 (LS-4) and the night illuminance constant (appendix). Night conditions were assumed, because the data sample was predominantly (70 percent) night.

The present study extends the scope of the original study as follows: (1) the night and day portions of the data sample were treated separately; (2) the 15-foot horizontal transmittance was substituted for the 5-foot horizontal transmittance as the base level. This more nearly approximated operational conditions, since 15 feet is the height of airfield transmissometer installations; and (3) the horizontal transmittances at discrete horizontal levels were used to determine the slant transmittances from 124 and 100 feet.

This enabled computation of slant to 15-foot horizontal visual range ratios from the heights of 100 and 124 feet for comparison with those from 155 feet.

DISCUSSION

DATA SAMPLE.

The data sample of the present study is the same as that of the previous study (Lewis and Schlatter, 1977). It consists of approximately 190 hours of minute-to-minute visibility observations in fog taken by six horizontal and one slant transmissometers mounted on two airfield towers at NAFEC. The data were collected from September 1972 to June 1973. The horizontal transmittance readings were taken at 5, 15, 49, 85, 124, and 155 feet over a 250-foot baseline. The slant reading was taken from 155 to 5 feet over a 290-foot baseline. Figure 1 shows the towers and instrumental configuration. The data were processed by electronic computer through a FORTRAN IV program.

DATA ANALYSIS.

The data were separated into day and night portions by assuming daytime conditions between sunrise and sunset, nighttime conditions between sunset and sunrise. Only observation sets associated with 15-foot visual range observations in runway visual range (RVR) steps 600- to 3,000 feet were analyzed. This range covers RVR category III (600-, 600, 800, and 1,000 feet), category II (1,200, 1,400, and 1,600 feet), a low portion of category I (1,800, 2,000, and 2,200 feet) and an intermediate portion of category I (2,400 2,600, 2,800, and 3,000 feet). (The category I minimum is normally the 1,800-foot RVR step, but becomes 2,400 feet when there is no touchdown zone and centerline lighting. See reference 2 for further information on RVR categories.)

The slant transmittances from 100 to 5 feet and from 124 to 5 feet were approximated by proportionately weighting and summing the average transmittance in discrete layers between 5, 15, 49, 85, and 124 feet. (The 100-foot horizontal transmittance was determined by interpolation between 85 and 124 feet.) The slant approximations should be very close for fog of vertical extent (the most common type--see tables 1 and 2, discussed later) and less accurate for shallow fog, depending on fog height with respect to a particular level.

The 155-foot slant transmittance was converted from a 290-foot baseline to a 250-foot baseline through the following exponential equation:

$$t_{250} = t_{290}^{(250/290)}$$

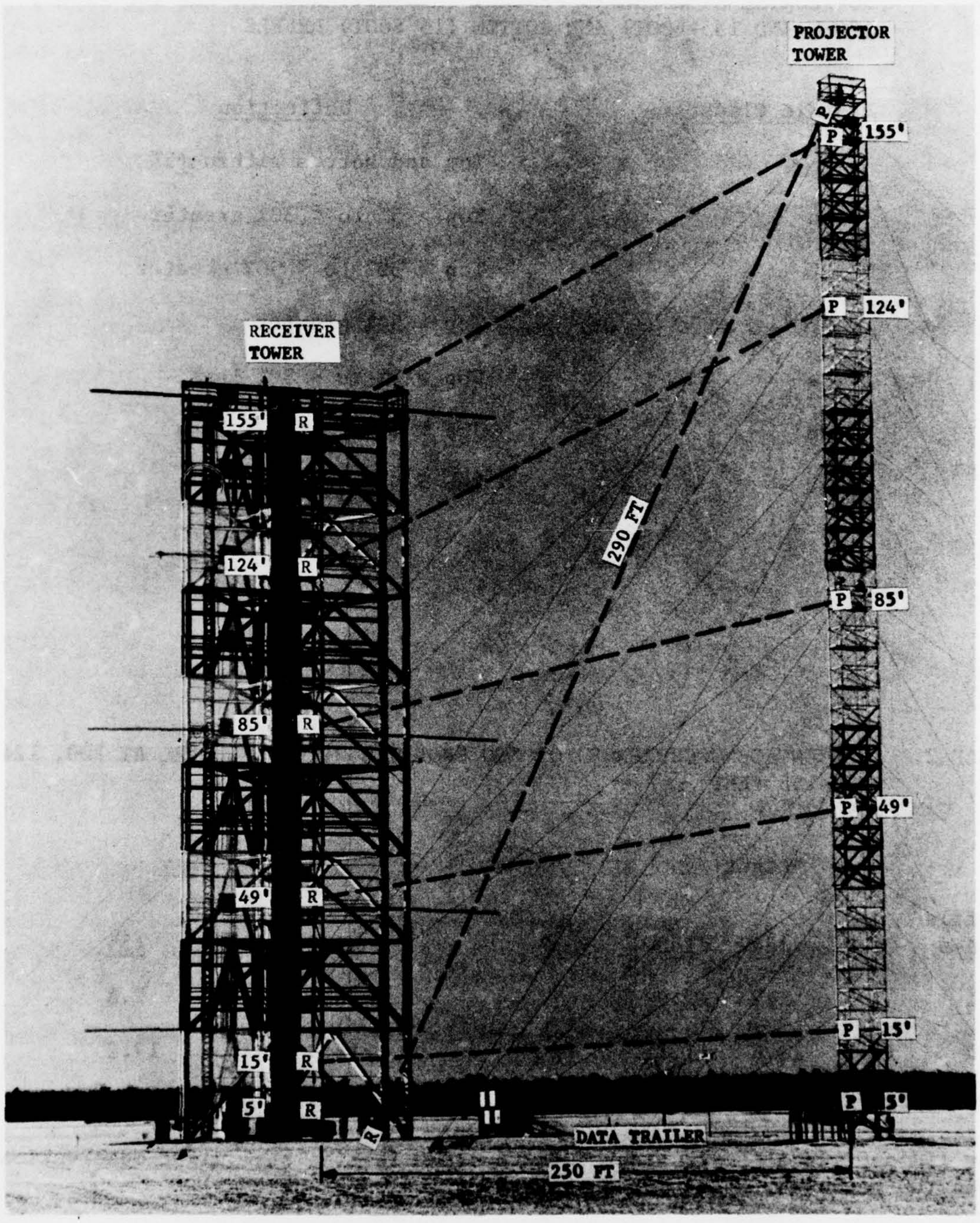

FIGURE 1. NAFEC METOWER FACILITY

TABLE 1. FOG PROFILE CLASSIFICATIONS BASED ON THE DIFFERENCE BETWEEN THE HORIZONTAL ATMOSPHERIC PERCENT TRANSMITTANCES AT THE TOP (100-, 124-, AND 155-FOOT) AND BOTTOM (15 FOOT) LEVELS

Profile Class	Definition
1	Top and bottom within ±5%
2a	Top > 5% to ≤ 30% greater
2b	Top > 30% to ≤ 50% greater
2c	Top > 50% greater
3a	Top > 5% to ≤ 30% less
3b	Top > 30% to ≤ 50% less
3c	Top > 50% less

TABLE 2. PERCENTAGE OCCURRENCES OF FOG PROFILES WITH TOP LEVEL AT 100, 124, AND 155 FEET

	*Night			*Day		
Profile Class	100	124	155	100	124	155
1	2.5	1.2	2.9	6.0	5.2	2.8
2	10.7	10.6	11.1	14.9	15.4	17.2
3	86.8	88.2	86.0	79.1	79.4	80.1

*For 15-foot visual range steps 600- to 3,000 feet. Total night observations 3,084 (69 percent); total day observations 1,415 (31 percent).

Where t is transmittance (expressed as a fraction) over the subscripted baseline.

The slant transmittances from 100, 124, and 155 feet and the 15-foot transmittance were converted to visual range using light setting 4 (LS-4) and the night illuminance constant for night observations, LS-5, and the day constant for day observations (appendix). The night percent transmittance range for RVR steps 600- to 3,000 feet is 0 to 54.5 percent. The corresponding day range is 0 to 77.7 percent.

FOG PROFILE CLASSIFICATIONS.

The data were organized according to linear fog profiles with height determined by the difference between the top (100-, 124-, 155-foot) horizontal percent transmittance and the bottom (15-foot) horizontal percent transmittance. Table 1 shows the profile classifications and top minus bottom percent transmittance differences.

The profile classifications of table 1 are quite similar to those of the previous study. The main difference is that profile 1 has been narrowed from ±10 to ±5-percent transmittance difference. This gave a better separation of slant to 15-foot horizontal visual range ratios near 1. Profiles 2a and 3a were enlarged accordingly. The percentage occurrences of profiles 1, 2, and 3 for the three heights of 100, 124, and 155 feet are shown in table 2.

Table 2 shows the dominance of profile 3 situations (fog [illegible]me vertical extent) for all three heights, both night and day. Profi[illegible]s have greater percentage occurrences for day versus night for all heights. This probably reflects the relatively greater frequency of radiation fog during the day (mostly early morning occurrence). The greater occurrences of profile 1's for 100 and 124 feet versus 155 feet for the day data probably reflect breakup of radiation fog where elements dissipate before reaching 155 feet.

PROFILE 3 VISUAL RANGE RATIOS.

Slant/15-foot horizontal visual range ratios were computed for heights of 100, 124, and 155 feet for profile 3 situations in the four subclasses within the 600- to 3,000 feet visual range step range (see DATA ANALYSIS section). The average ratios ranged from about 0.80 to 0.50, decreasing with increasing skewness of the profile (3a to 3b to 3c). Standard deviations were generally less than 0.1. This character indicated a potential for a linear correlation/regression analysis using ratio and transmittance difference between top and bottom levels as arguments. This analysis was made and showed that one regression equation was sufficient to define the 600- to 3,000 feet range for each height. Table 3 shows the results for night data, table 4 for day data.

Tables 3 and 4 show that the slant/15-foot horizontal visual range ratio is highly correlated with transmittance difference between top and bottom levels. The standard errors of estimate (SY's) are low and show a trend toward more accuracy of prediction with lower slant height. Compared with the standard deviation of ratios (SIGY's), the SY's indicate that the regression relationships have decreased the scatter by roughly 50 percent.

TABLE 3. LINEAR CORRELATION/REGRESSION PARAMETERS FOR PROFILE 3 OBSERVATIONS, NIGHT

*HT(ft)	r	$\bar{Y}$	SIGY	$\bar{X}$(%)	SY	A	B	No. Cases
100	0.89	0.79	0.06	-19.1	0.03	0.917	0.007	2,678
124	.85	.75	.07	-23.5	.04	.901	.006	2,720
155	.85	.69	.11	-24.3	.06	.915	.009	2,653

*Table is for 15-foot visual range steps 600- to 3,000 feet (transmittance range 0 - 54.4 percent, LS-4 night); HT is height of top level in feet; r is the linear correlation coefficient between slant/15-foot visual range ratio and top level (100, 124, 155 feet) minus bottom level (15 feet) transmittances; $\bar{Y}$ is average slant/15-foot visual range ratio; SIGY is the standard deviation of Y; $\bar{X}$ is the average top-minus-bottom transmittance difference (%); SY is the standard error of estimate for the line of regression (Y = A + B X); A and B are the regression coefficients.

TABLE 4. LINEAR CORRELATION/REGRESSION PARAMETERS FOR PROFILE 3 OBSERVATIONS, DAY

*HT(ft)	r	$\bar{Y}$	SIGY	$\bar{X}$(%)	SY	A	B	No. Cases
100	0.93	0.75	0.08	-26.4	0.03	0.929	0.007	1,119
124	.90	.71	.09	-31.5	.04	.903	.006	1,124
155	.79	.62	.13	-33.3	.08	.855	.007	1,133

*Table is for 15-foot visual range steps 600- to 3,000 feet (transmittance range 0 - 77.7 percent, LS-5 day). See table 3 for further explanation.

The average slant/15-foot horizontal visual range ratios ($\bar{Y}$'s) decrease with increasing height, consistent with the profile 3 fog structure of decreasing transmitttance with height. This is also shown by the increasing (negative sense) average transmittance difference between top and bottom levels ($\bar{X}$'s) with increasing height of top level. The lower $\bar{Y}$'s and higher $\bar{X}$'s (negative sense) for the day data, reflect the greater range for transmittance dropoff with height. This is because the 15-foot day transmittance can go to 77.7 percent, versus 54.5 percent for night.

Predictions of SVR in terms of RVR and linear fog density measurement with height should be reasonably accurate for profile 3 situations. The regression equations of tables 3 and 4 indicate that this could be done to within one 200-foot step of actual for the 155-foot slant, probably more accurately for the lower levels.

PROFILE 1 AND 2 VISUAL RANGE RATIOS.

Slant/15-foot horizontal visual range ratios were computed for heights of 100, 124, and 155 feet for profile 1, 2a, 2b, and 2c samples in the four subclasses within the 600- to 3,000 feet range. The profile 1 results showed that the average ratios were typically near 1, with standard deviations of about 0.1 to 0.2. The subclass samples for each height were combined into larger ones for the 600- to 3,000-foot range, since these reflected the essential character of the data. Table 5 shows both the night and day summaries.

TABLE 5. PROFILE 1 AVERAGE SLANT/15-FOOT VISUAL RANGE RATIOS AND STANDARD DEVIATIONS

	*Night			*Day		
HT(ft)	Avg. Ratio	Std. Dev.	No. Cases	Avg. Ratio	Std. Dev.	No. Cases
100	0.95	0.07	75	0.91	0.05	85
124	0.93	.09	75	0.93	0.09	74
155	0.89	.15	89	0.94	0.21	39

*For 15-foot visual range steps 600- to 3,000 feet.

Table 5 shows that ratios average near 1 with standard deviations increasing with height. The magnitudes of the deviations indicate that SVR could be reasonably estimated to be not more than one 200-foot step below RVR for 100 and 124 feet, less reliably within that limit for 155 feet. The requirement for such estimates would, however, be small in view of the low frequencies of occurrence of profile 1 situations (table 2).

The profile 2 results showed that average slant/15-foot horizontal visual range ratios became increasingly greater than 1 with progression from profile

2a to 2b to 2c. The average ratios ranged from about 1 to 5, with standard deviations ranging from 1/4 to 3. The variability reflects the essentially radiation fog character of profile 2 situations. The average ratios and standard deviations of ratios mostly increased with height, consistent with the increase in transmittance with height.

A linear correlation/regression analysis would not do for profile 2 situations in view of the variability. Rather, the data have been organized to show simply the percentages of individual ratios equaling or exceeding values of 1.0 and 1.5. The subclasses were combined into one class covering the 600- to 3,000 feet range for this analysis. The night data are shown in table 6, the day data in table 7.

Tables 6 and 7 show, as would be expected, increasing percentages of individual ratios equal to or greater than 1.0 and 1.5, with progression from profiles 2a to 2b to 2c. A significant difference in the night and day distribution is the dominance of the night samples by profile 2c situations. This is related primarily to the requirement for the top transmittance to be more than 50 percent higher than the bottom (15-foot) transmittance for profile 2c. Thus, the lower 15-foot transmittance range for the night data (0 to 54.5 percent versus 0 to 77.7. percent, day) allows more situations to qualify.

Predictions of SVR from RVR and profile measurement cannot be exact with profile 2 situations. However, qualitative estimates in terms of the probability that SVR exceeds RVR by certain amounts could be made and should be useful in warning pilots of the impending decrease in visibility to the RVR value at runway level.

TABLE 6. PROFILE 2 AVERAGE SLANT/15-FOOT VISUAL RANGE RATIOS AND PERCENTAGES ≥1.0 AND 1.5, NIGHT*

	Profile 2a				Profile 2b				Profile 2c			
Height (ft)	No. Cases	Avg. Ratios	% ≥1.0	% ≥1.5	No. Cases	Avg. Ratios	% ≥1.0	% ≥1.5	No. Cases	Avg. Ratios	% ≥1.0	% ≥1.5
100	33	1.14	94	0	87	1.69	100	45	211	2.40	100	99
124	7	1.18	86	14	51	1.96	100	73	270	2.66	100	97
155	15	0.92	27	0	37	2.79	95	86	290	3.63	99	93

*Table is for 15-foot visual range steps 600- to 3,000 feet (transmittance range 0-54.5 percent, LS-4 night).

TABLE 7. PROFILE 2 AVERAGE SLANT/15-FOOT VISUAL RANGE RATIOS AND PERCENTAGES ≥1.0 AND 1.5, DAY*

	Profile 2a				Profile 2b				Profile 2c			
Height (ft)	No. Cases	Avg. Ratios	% ≥1.0	% ≥1.5	No. Cases	Avg. Ratios	% ≥1.0	% ≥1.5	No. Cases	Avg. Ratios	% ≥1.0	% ≥1.5
100	61	1.24	77	18	71	1.61	100	48	79	2.34	100	90
124	51	1.40	82	43	76	1.70	91	57	90	2.58	100	96
155	63	1.46	57	37	87	2.23	91	68	93	2.66	96	86

*Table is for 15-foot visual range steps 600- to 3,000 feet (transmittance range 0-77.7 percent, LS-5 day).

CONCLUSION

Measurements of atmospheric transmittance near the surface and at a level near 100, 125, or 150 feet can provide a basis for making operationally useful estimates of SVR/RVR ratio.

RECOMMENDATION

The recommendation of this report is the same as in the original study (reference 1); i.e., "conduct further studies to determine if fog profile relationships to SVR/RVR ratios are valid when the high-level transmissometer is separated from the low-level (runway touchdown) transmissometer by a few thousand feet." (This would correspond to an operational configuration where the high level transmissometer (very short baseline type) was mounted on an existing airfield tower or on the control tower some distance away from the runway touchdown transmissometer.)

REFERENCES

1. Lewis, W., and Schlatter, E., Slant and Runway Visual Range Relationships, U.S. Dept. of Transportation, FAA, SRDS, Washington, D.C., FAA-RD-77-34, June, 1977.

2. Runway Visual Range (RVR), Federal Aviation Administration Advisory Circular, AC No. 97-1, November 4, 1976.

APPENDIX

DETERMINATION OF RUNWAY VISUAL RANGE

At night and under daytime conditions when the high-intensity runway edge lights are the most dominant target for the pilot's sighting, RVR is derived from Allard's Law:

$$E_t = \frac{I(t_b)^{V/b}}{\frac{V^2}{5280}}$$

where:

E_t = pilot's visual illuminance threshold (mile-candles)

I = intensity of light target (candelas)

t = atmospheric transmittance (fraction)

b = path length over which atmospheric transmittance is sampled (feet)

V = visual range from pilot to appropriate light target, RVR (feet)

Under certain bright daytime conditions when the meteorological visibility of objects contrasted against the sky yields a greater visual range than light targets, RVR is derived from Koschmieder's Law:

$$e_o = (t_b)^{V/b}$$

where:

e_o = pilot's contrast threshold (dimensionless)

t = atmospheric transmittance (fraction)

b = path length over which atmospheric transmittance is sampled (feet)

V = visual range from pilot to appropriate contrast target, RVR (feet)

Inputs to the RVR equations are selected empirical constants and measurements made by relatively simple instruments. Currently, they are:

1. e_o. Empirically selected as .055.

2. E_t. Empirically selected as 1,000 mile-candles under daylight conditions, and 2 mile-candles at night.

3. t. A measurement by a transmissometer of the transmittance of light made along a specified path in the aircraft landing/takeoff zone.

4. b. The path length for t (feet).

5. I. The representative step intensities (light settings) of the high-intensity runway edge lights have been accepted as step 5, 10,000; step 4, 2,000; and step 3, 400 candelas.

6. Day/night. Divided by incident illumination of about 2 footcandles as determined by an elementary illuminometer.

It should be noted that while a single value of e_o and two of E_t are used in practice, actual values may vary widely between and within individual pilots, depending on human factors and observational environment.